ESD safety training

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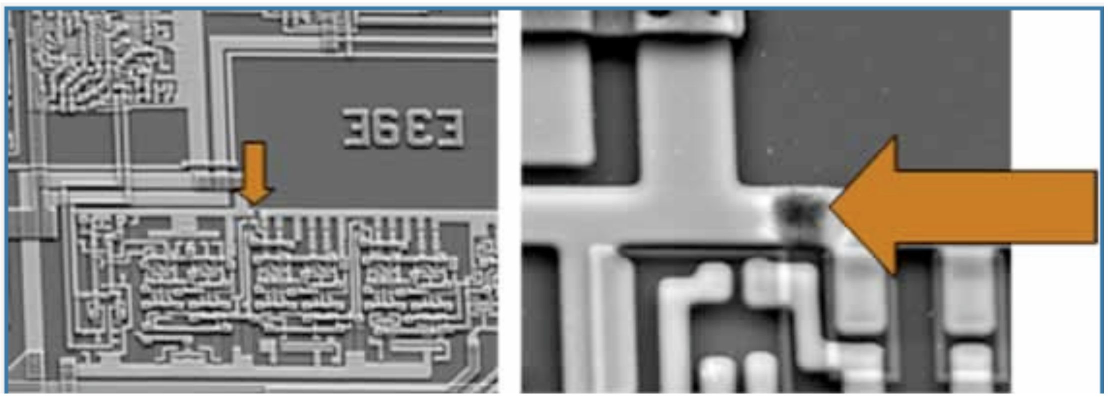
Static is not *always* fun!



It can lead to damage of sensitive semiconductor devices

OUTLINE

- *Introduction to ESD and CCDs*
- *Video about ESD safety*
- *CCD ESD Training; Beyond The Video…*

Static charge

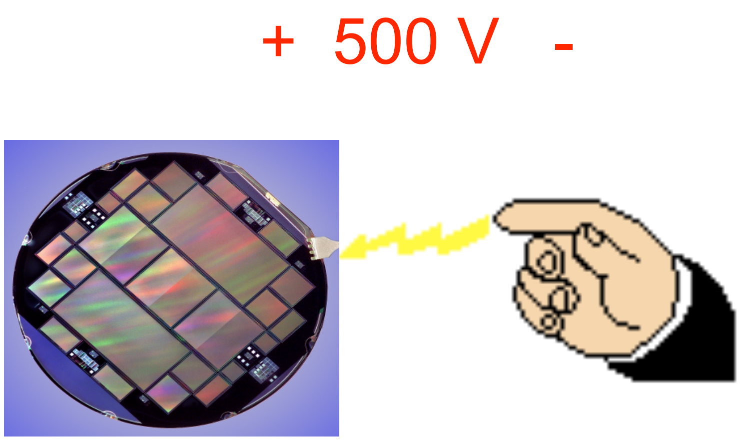
- Electrostatic electricity is an imbalance of positive and negative charges on the surface of objects.
- For example, a person can generate static charge while walking across the floor.
- The human body can charge to 100s or 1000s of volts.

\+ 500 V -

Static charge

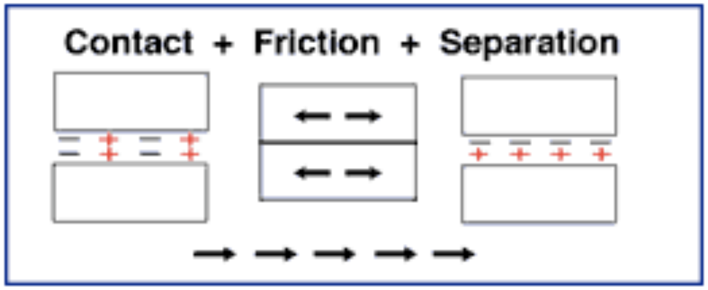
- Once charged, discharge from the finger tip to a CCD is possible, creating an electrostatic discharge (ESD) event.

- The tiniest spark requires about 500 V, which is approximately 10 times what a typical CCD gate dielectric can withstand before damage results.



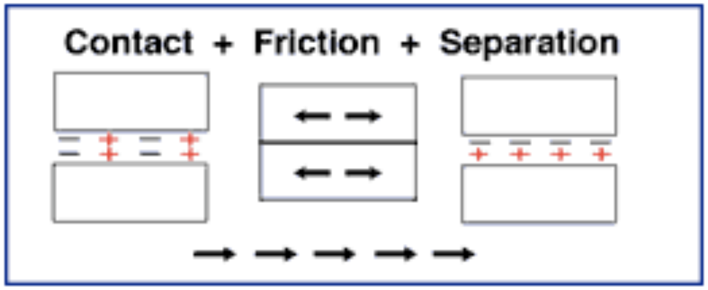
Triboelectric effect

- How does the imbalance of charge get created?
- One very common way is to rub two objects together.
- If they are made of different materials and are both insulators electrons may be transferred from one to the other.
- The more rubbing, the more electrons move, and the larger the static charge that builds up.
- This is called the triboelectric effect
  - Tribo- means ‘to rub’.



Triboelectric effect

- Note: It is not the rubbing or friction that causes electrons to move.
- It is simply the contact between two different materials.
- Rubbing just increases the contact area between them.



Triboelectric series

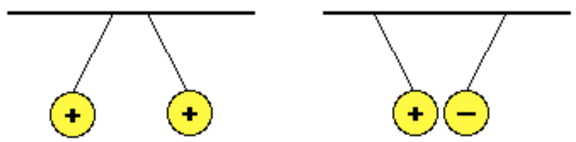
- When we rub two different materials together, which becomes positively charged and which becomes negative?
- Materials have been ranked according to their ability to hold or give up electrons.
- This ranking is called the triboelectric series.
- When 2 materials are rubbed together, the one higher on the list will give up electrons and become positively charged.

TRIBOELECTRIC SERIES

your hand
glass
your hair
nylon
wool
fur
silk
paper
cotton
hard rubber
polyester
polyvinylchloride plastic

Why does your hair stand up after you take your hat off?

- When you pull your hat off, it rubs against your hair.
- Electrons move from your hair to the hat.
- Now each of the hairs has the same positive charge.
- Things with the same charge repel each other.
- So the hairs try to move away from each other.
- The farthest apart they can get is to stand up and away from all the other hairs.



Humidity

- If it is very humid, the charge imbalance will not remain for long time.

- If the humidity is high, the moisture coats the surface of the material, providing a low-resistance path for electron flow.

- This path allows the charges to "recombine" and thus neutralize the charge imbalance.

- If it is very dry, a charge can build up to extraordinary levels, up to tens of thousands of volts!

Table I - Typical Electrostatic Voltage

	Electrostatic Voltages	
Means of Static Generation	10-20 percent Relative Humidity	65-90 percent Relative Humidity
Walking across carpet	35,000	1,500
Walking over vinyl floor	12,000	250
Worker at bench	6,000	100
Vinyl envelopes for work instructions	7,000	600
Common poly bag picked up from bench	20,000	1,200

Humidity is not enough

- As the table shows, triboelectric charging persists even at high relative humidity.
- Humidity control does limit the triboelectric charging process, but humidity does not eliminate the need for all of the conventional safeguards!

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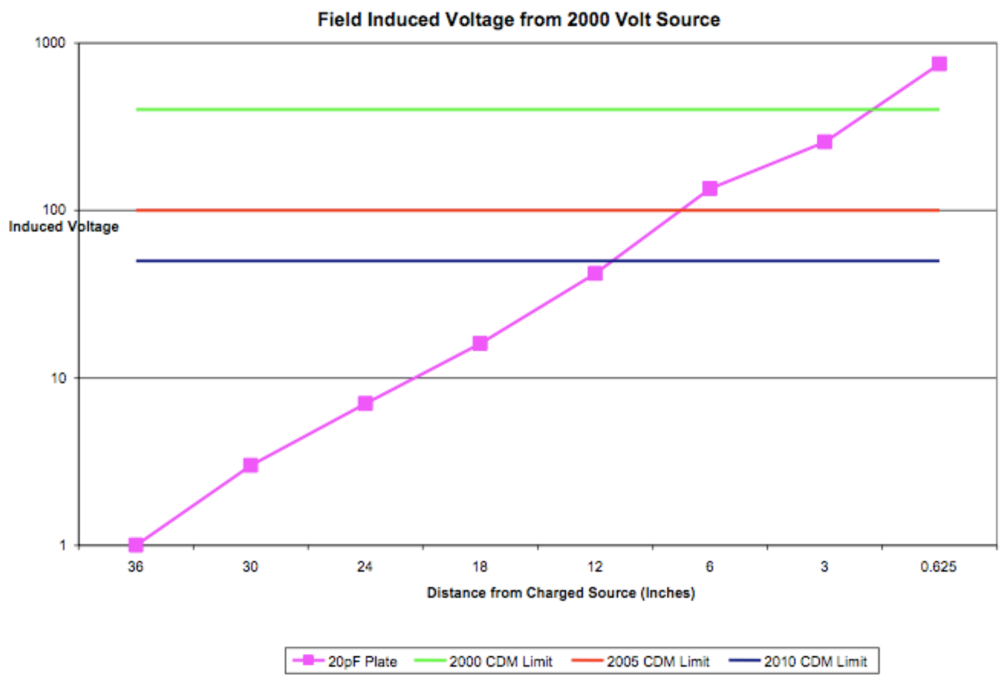
Charging by induction

- Field Induced Charge Device Model damage from an electrostatic field occurs when a charged item is brought into close proximity to an ESD sensitive device and the device is then grounded while in the presence of the field.
- Keep unsafe materials and unprotected people at least 3 feet away from the ESD sensitive devices.



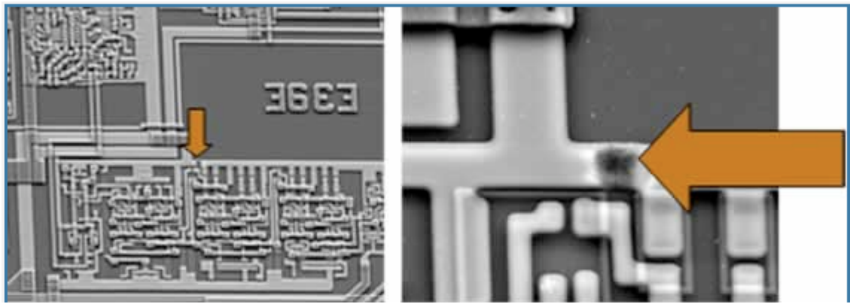
Static charge and CCDs

- The CCD is one of the most ESD-sensitive electronic components manufactured.

- Without ESD protection diodes, most scientific CCDs are susceptible to a discharge as small as 50 V.

- An ESD event can cause bus lines to melt, generate ESD craters, diode junction breakdown, or insulator failure.

- “Of these problems, dielectric damage is by far most prevalent.”*

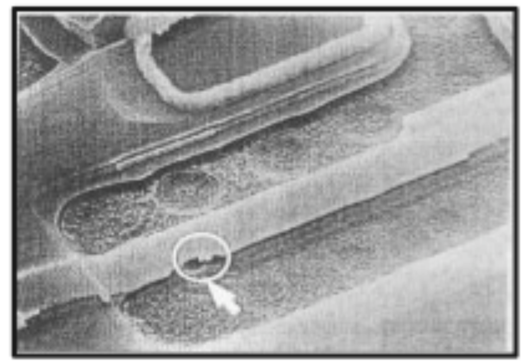


**Scientific CCDs*, J. R. Janesick

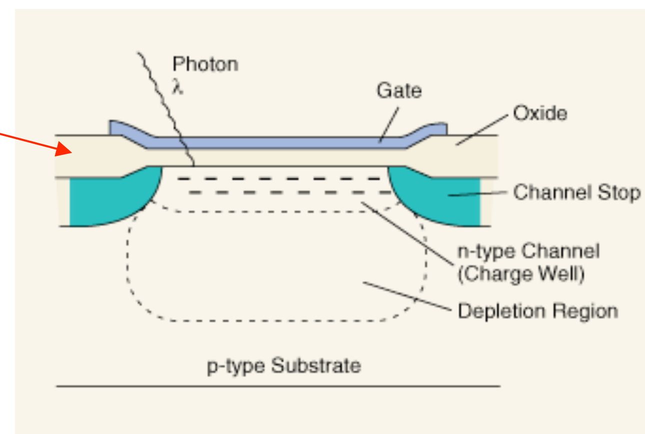
Static charge and CCDs

- Although any semiconductor device can be damaged by a spark, MOS (Metal Oxide Semiconductor) devices are particularly susceptible.
- This is because the energy stored in the *gate-channel capacitance*, when it has been brought up to breakdown voltage, is sufficient to blow a hole through the delicate *gate oxide insulation*.*
- The gate oxide insulation is the *dielectric* mentioned in the previous slide.

**The Art of Electronics*, Horowitz and Hill

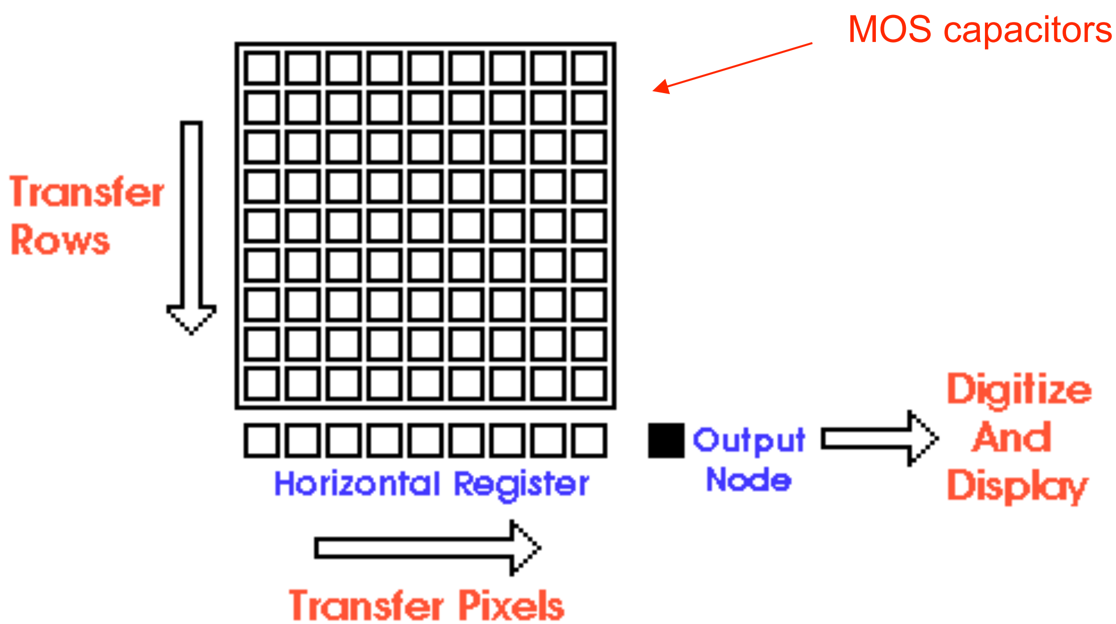


Gate oxide damage to an input buffer

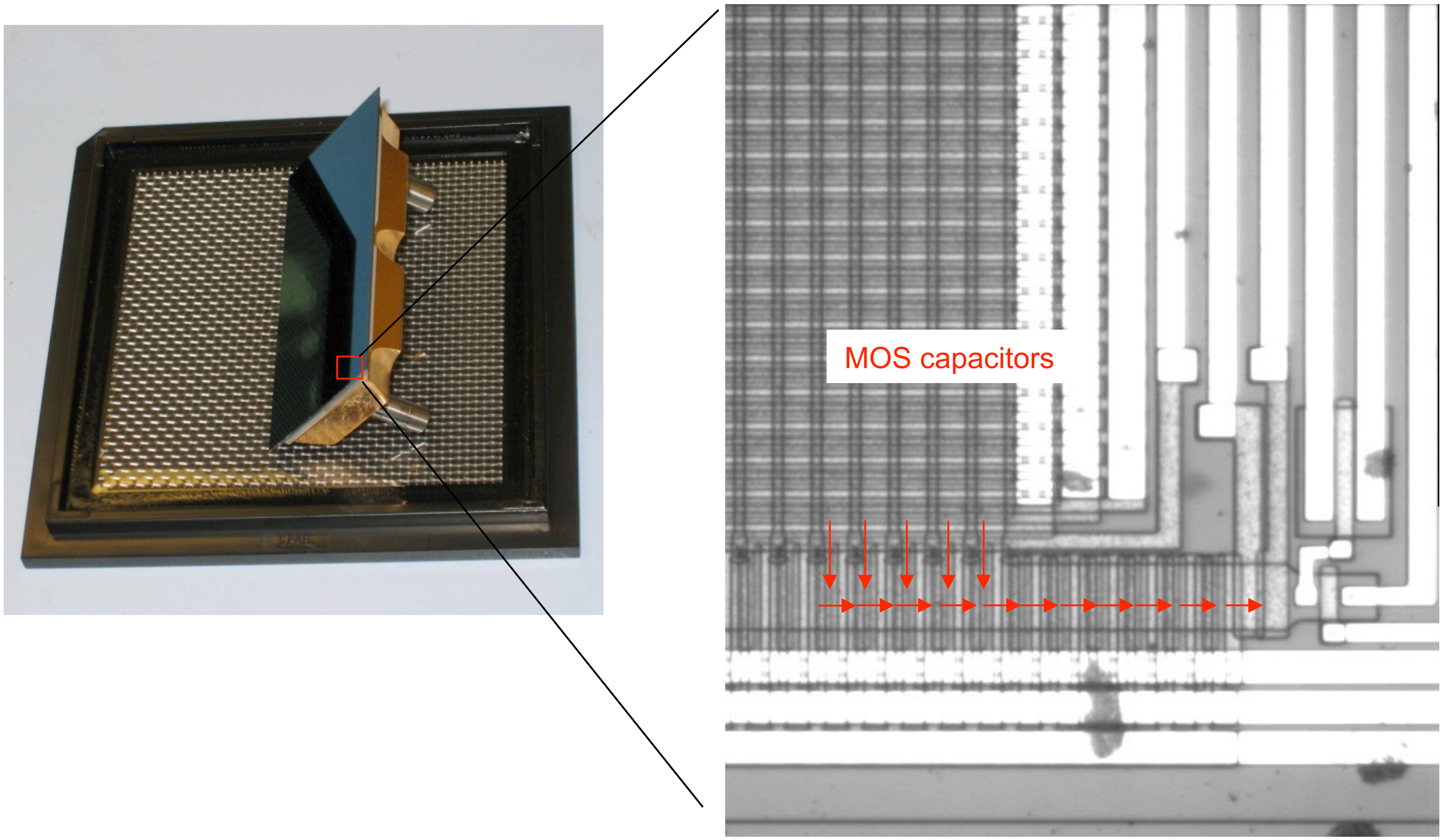


MOS devices

- These particularly susceptible MOS devices are exactly what a CCD is comprised of
- A CCD is a huge array of several million MOS capacitors!



CCD layout

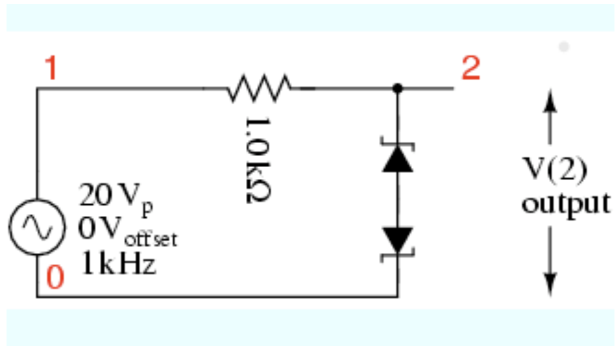


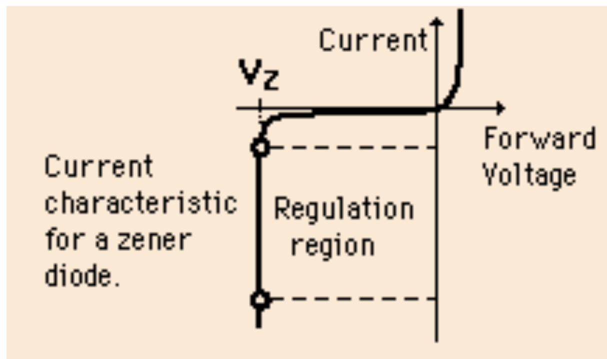
Dark Energy Survey CCD 700x

CCD operation is described in the Appendix

An example of ESD protection for CCDs

- e2v (a commercial CCD vendor) manufactures CCDs for astronomical applications
  - e2v CCDs are used on CFHT, HST, SWIFT, and many more ground and space based telescopes
- They use on-chip back-to-back zener diodes for ESD protection on all the gates
  - This works for bipolar signals
- This is one of several techniques that can be used to help minimize susceptibility to ESD damage
- A more-detailed description of the operation of this protection circuit is in the Appendix.





However, it’s important to know that DES CCDs do *not* have any on-chip ESD protection.

The need to practice ESD-safe procedures

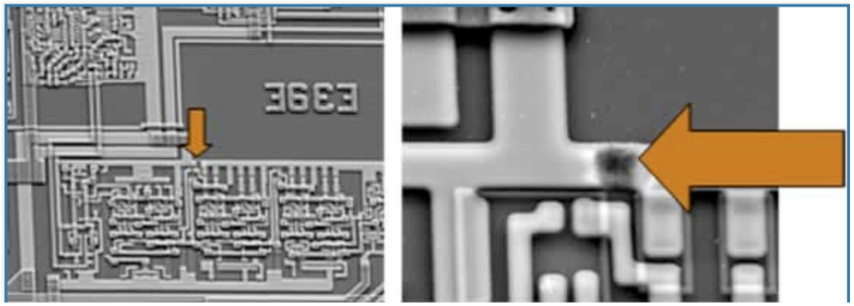
- ESD gate protection helps, but it is not perfect
  - The most vulnerable (small) gates do get useful protection.
  - But very fast ESD spikes can still get through, and transistor drains are not protected.
- Therefore there is no substitute for careful procedure.

The need to practice ESD-safe procedures

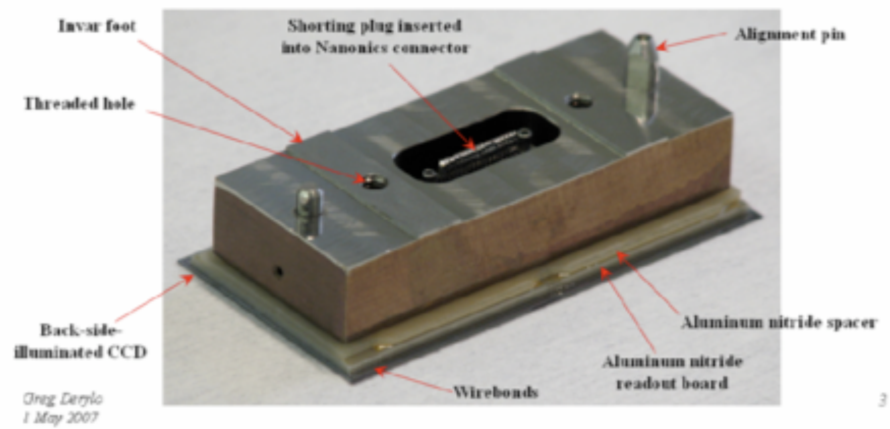
- There is also a concern about non-fatal ESD damage.
  - This could manifest itself as delayed failure or performance degradation, both of which are bad news.
- Again, there is no substitute for careful procedure.

Front-illuminated vs. back-illuminated CCDs

- For bare wafers or front-illluminated chips it is sometimes possible to view ESD damage under a microscope.



- However, our CCDs are back-illuminated, and, once packaged, it is not possible to see the damage.
  - Fault analysis is harder or impossible.



The need to practice ESD-safe procedures

- Internal ESD protection networks of resistors and clamping diodes can sometimes compromise performance (speed, noise, etc.), complicate device design, or cause luminescence.

An example of amplifier luminescence can be seen in the upper left hand corner of this image. Luminescence could also be caused by a conducting diode.

The need to practice ESD-safe procedures

- Therefore, at Fermilab, ASIC designers often rely on the skill and care of the technicians to practice ESD safe procedures when packaging, installing, and testing devices rather than sacrificing performance or complicating the design by including internal protection.*

*Jim Hoff, Fermilab ASIC Designer

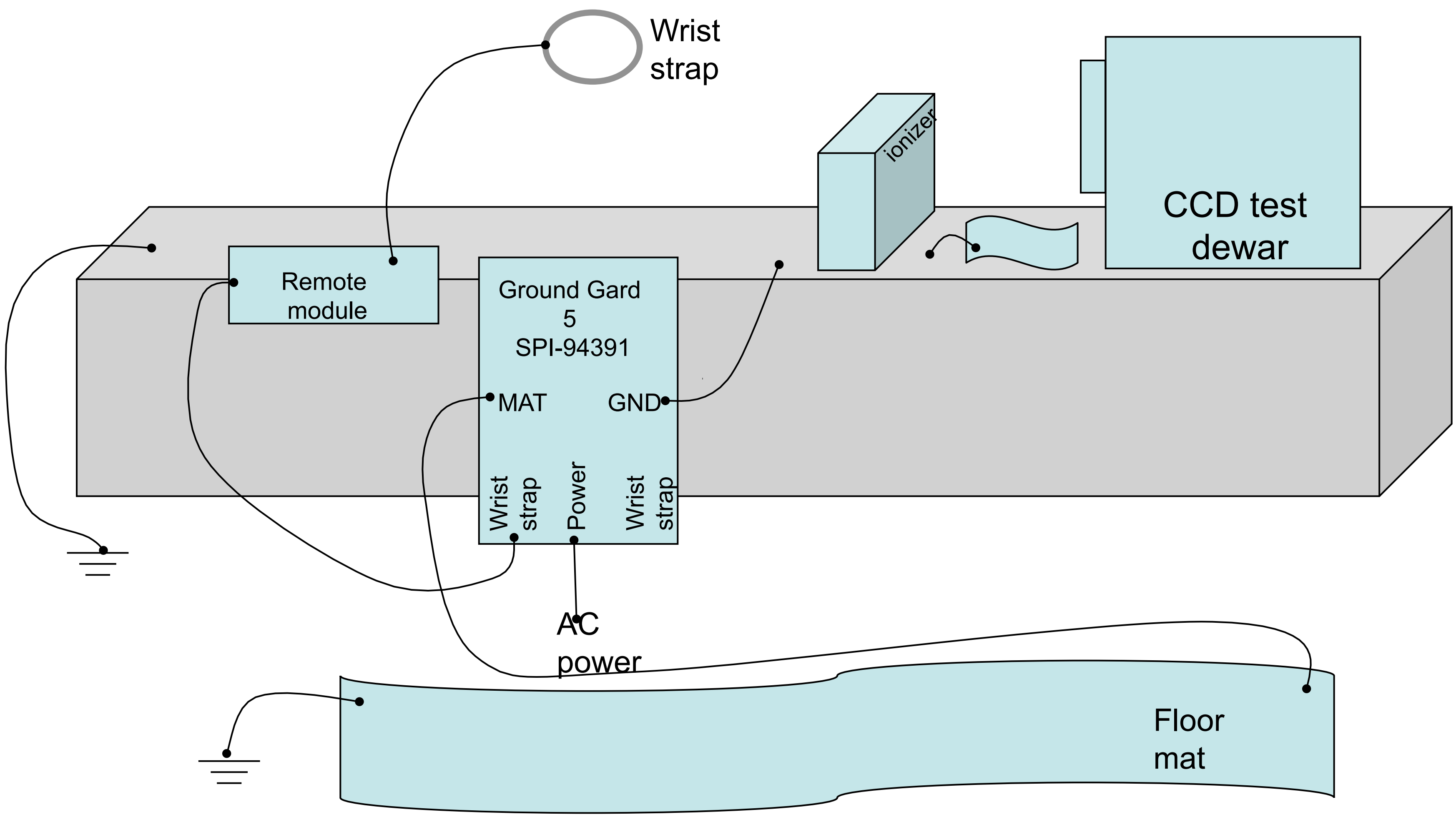
The need to practice ESD-safe procedures

- Similarly, the DES and SNAP CCDs have no ESD protection

- Therefore we must follow all ESD safety procedures very carefully to minimize the chance of damaging the CCDs.

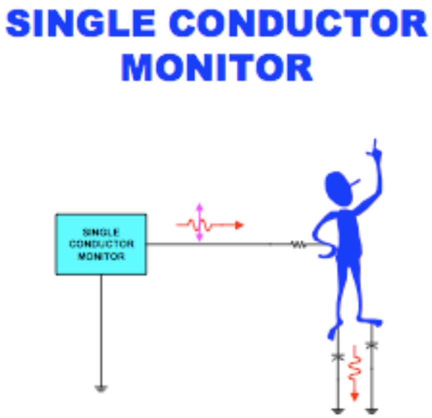
- These procedures will be explained in the video followed by a review by Greg, with our CCDs in mind.

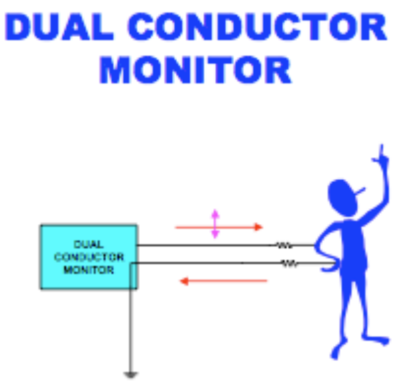
Continuous ESD monitoring



Types of continuous wrist strap monitors

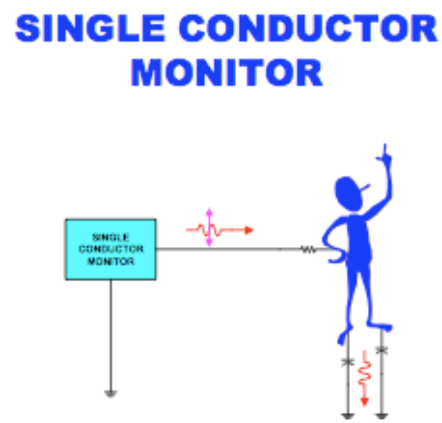
- There are several systems of continuous wrist strap monitors.
- The most common are
  - Single conductor monitors
  - Dual conductor monitors

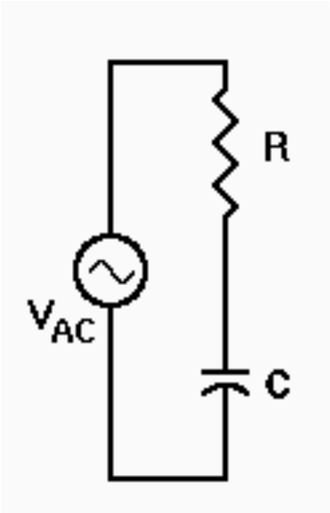




Single conductor continuous wrist strap monitors

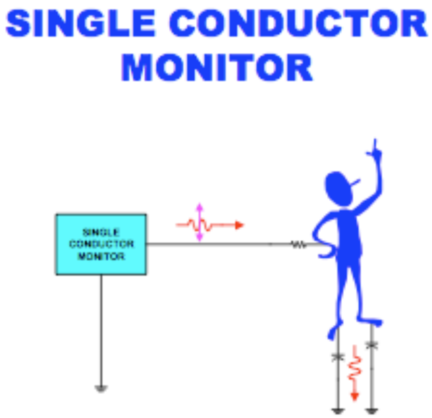
- The wrist strap monitors we currently use are single conductor monitors
- A person can be thought of as a plate of a capacitor with the other plate being ground.
- The “plates” are separated by an insulator as shoes and mats.
- The person and the resistors built into the wrist strap and connecting cords form the resistor.

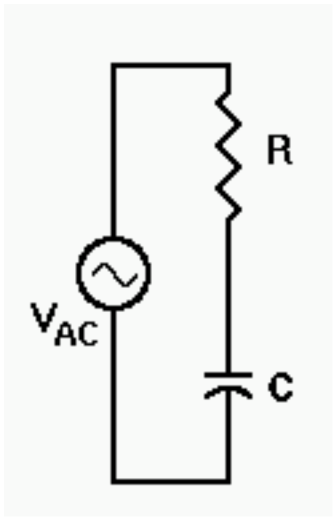




Single conductor continuous wrist strap monitors

- A tiny AC current applied to this circuit provides a way to measure whether the circuit is complete.
- Any break will cause a higher impedance that can be used to trigger an audible alarm.



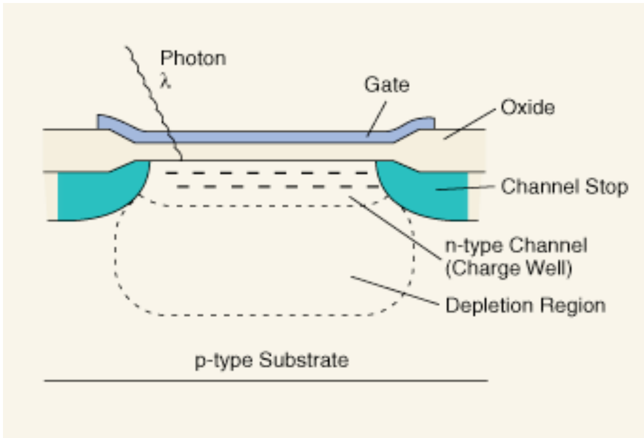


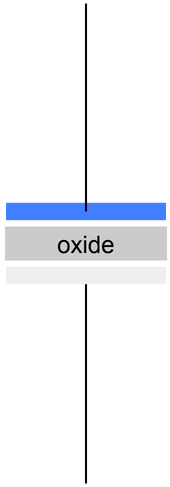
Appendix A

CCD structure and operation

CCD structure

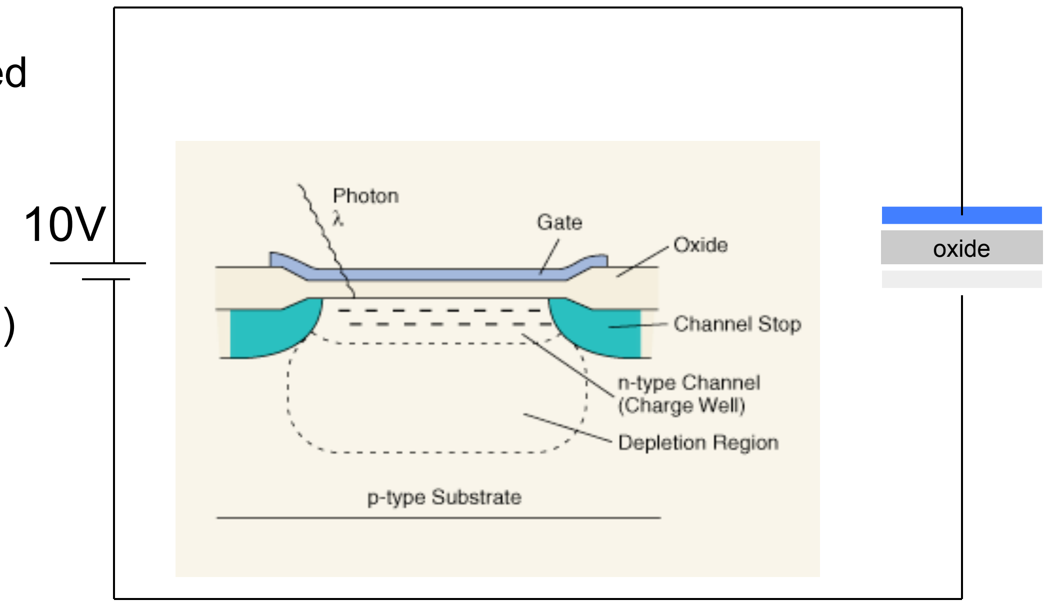
- MOS capacitor
  - Metal Oxide Semiconductor
- Most common to use p-type substrate
  - Note: DES CCDs use n-type
- Holes are majority carriers in p-type.
- There are a few electrons from thermal energy (minority carriers)





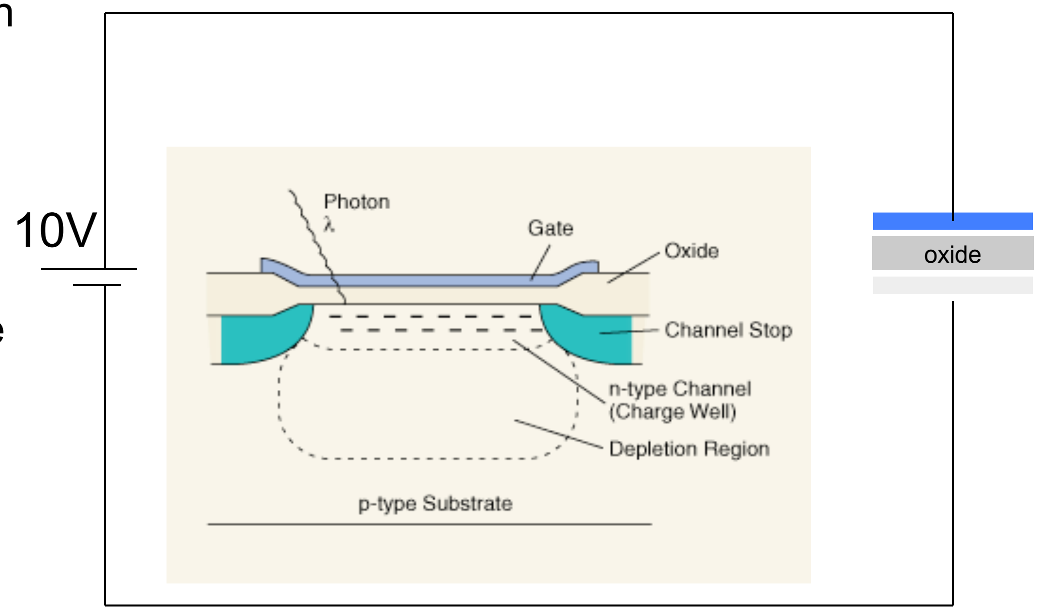
CCD operation

- Bias gate (typical 10 V)
- Majority carriers (holes) are pushed back into interior of substrate
- A zone almost free of majority carriers is then created at the SiO_2-Si interface (depletion region)



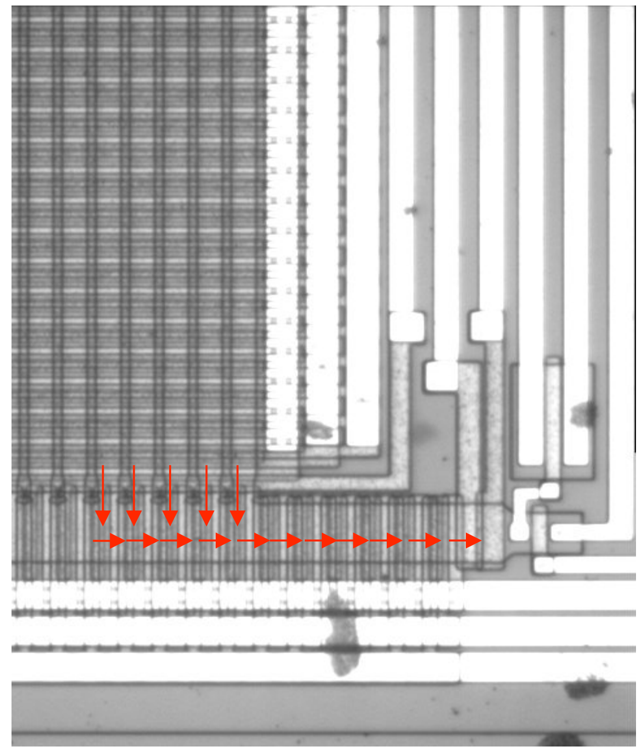
Charge injection

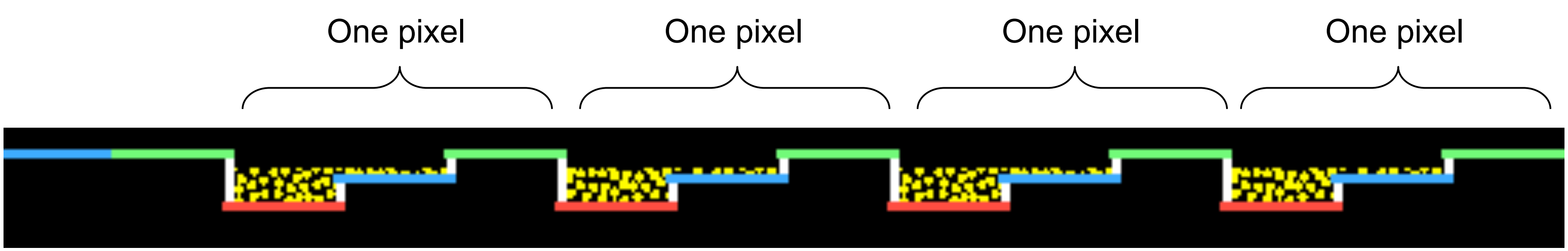
- Electron-hole pairs are created as photons pass through the depletion region
- These pairs are separated by the potential.
- The electrons accumulate near the SiO_2-Si interface forming an n-channel
- This is also called the inversion layer
- The inversion layer carries the information



Charge transfer

- After the integration time has elapsed, the charges are read out.
- Example shown is the most common, three phase transfer, which is used for the DES CCDs.
- Note that the gate voltages swing both positive and negative.





Appendix B

An example of ESD protection for CCDs

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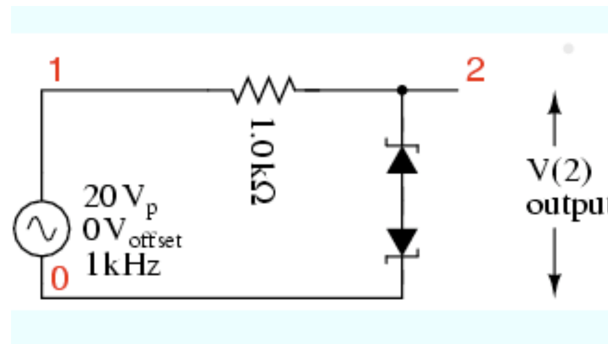

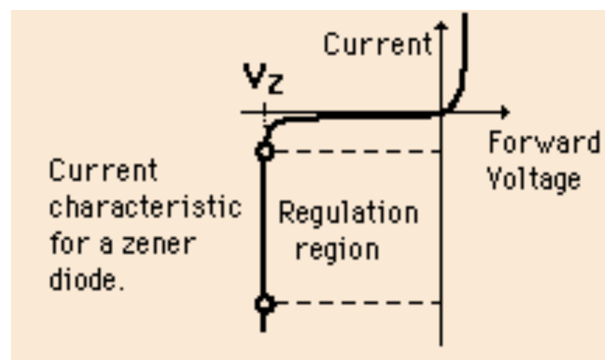

Back-to-back zeners

- For example, assuming a zener breakdown voltage of 10 V, back-to-back zener diodes will clip both +/-10 V.
  - For a positive half-cycle, the top zener is reverse biased, breaking down at the zener voltage of 10 V.
  - The lower zener drops approximately 0.7 V since it is forward biased.
  - Thus, a more accurate clipping level is 10+0.7=10.7V.
- Similar negative half-cycle clipping occurs at -10.7 V.